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GPS CAPABILITIES FOR THE WARFIGHTER

by

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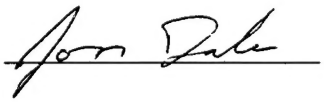
A paper submitted to the Faculty of the Naval War College in partialsatisfaction of the requirements of the Department of Joint MilitaryOperations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of theNavy.

Signature 

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15.Abstract: The Global Positioning System (GPS) is a space-based worldwide navigation system that has a wide range of military and civil applications. The vastly increased situational awareness and accurate positioning capabilities provided by this system act as a force multipliers for today's smaller military. Increased situational awareness, as well as navigation and reconnaissance capabilities will support decisions regarding maneuver and application of forces. GPS will be used to guide weapons and vehicles, support combat identification and search and rescue missions, track troops and supplies, and much more. There are limitations to the system, such as potential signal jamming or enemy use, that must be controlled in order to maintain this valuable asset. GPS is an extremely useful tool which has the capability to greatly enhance the military's warfighting ability. The successful commander must understand the capabilities and limitations of GPS technology to effectively utilize it's many applications on the battlefield.

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Abstract of

GPS CAPABILITIES FOR THE WARFIGHTER

The Global Positioning System (GPS) is a space-based worldwide navigation system that has a wide range of military and civil applications. The vastly increased situational awareness and accurate positioning capabilities provided by this system act as a force multipliers in today's smaller military. Use of this system provides a universal geographic grid that, when used by joint and combined forces allows close coordination for supporting operations with reduced risk of friendly fire casualties.

GPS technology will have a significant effect on a wide variety of military missions. Increased situational awareness, as well as navigation and reconnaissance capabilities will support decisions regarding maneuver and application of forces. GPS will be used to guide weapons and vehicles, support combat identification and search and rescue missions, track troops and supplies, and much more. There are limitations to the system, such as potential signal jamming or enemy use, that must be considered and controlled in order to maintain this valuable asset.

GPS is an extremely useful tool which has the capability to greatly enhance the military's warfighting ability. The successful commander must understand the capabilities and limitations of GPS technology to effectively utilize it's many applications on the battlefield.

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INTRODUCTION

The Global Positioning System (GPS) has brought about a revolution in the way we capture and use geospatial information. This paper discusses ways in which this system can be utilized to provide enhanced capabilities to the operational commander. GPS is a satellite based navigation system fielded by the Department of Defense for joint civil and military use. Now fully operational, both defense and civilian industries are finding innovative ways to exploit GPS capabilities.

As the military downsizes, greater emphasis is placed on the use of technology to offset force reductions. The exploitation of GPS is one of the facets of this technology explosion in military affairs. The commander can better utilize the three key operational factors of space, time, and forces, through reliance on GPS technology. Reconnaissance, maneuver, operational fires, application of forces, sequencing, synchronization, phasing and coordination will all benefit from the unique positioning and timing capabilities provided from GPS.

Unfortunately, there are shortcomings to dependence on GPS. The signals could be jammed by enemy forces, or could be used by the enemy. Protection of the integrity of the system must be maintained, along with preventative measures against potential enemy exploitation. There also exist certain physical limitations to signal reception. In spite of the drawbacks, GPS has proven to be an extremely useful and capable tool for the military.

This paper will begin with a general description of the components and operation of GPS. Current and future systems utilizing GPS and their effects on military operations will then be explored. A wide range of applications will be covered to highlight the far reaching benefits to the warfighter derived from this single system. Reliance on any system carries with it the risk of a

loss of effectiveness should the system be degraded or destroyed. The risks and limitations of GPS will be discussed, as well as the measures available to limit these liabilities.

It is important that the operational commander be aware of the various applications of GPS technology that can be used as force multipliers on the battlefield. GPS enhancements to military systems are here today, it is up to the military professional to effectively utilize them, and to protect this valuable asset.

THE GLOBAL POSITIONING SYSTEM

The Global Positioning System (GPS) is a space-based, worldwide, all-weather, navigation system developed and fielded by the U.S. Department of Defense. The system, which was designed for both military and civilian utility, became fully operational in early 1995.[1] Today it provides accurate, continuous, three-dimensional positional and temporal information for a wide variety of applications.

GPS is a satellite based radio-navigation system consisting of three major segments: space, control, and users. The space segment is a network of 21 primary satellites, along with three active spares, located in such a way that a minimum of four will always be in view from any point on Earth. The satellites are placed into six orbital planes, each tipped at 55 degrees to the equator, where they track a twelve hour orbit, 10,898 nautical miles above the Earth.

The space segment transmits timing pulses and satellite ephemeris data in coded radio signals. The ephemeris data provides sixteen constants that are used to determine the exact location of each satellite. To provide the precise timing measurements necessary for proper operation of the

GPS, four extremely accurate atomic clocks are carried on each satellite. Each clock is so accurate and stable that it will only gain or lose one second over 160,000 years.

GPS works by determining the time required to receive the radio signal from a satellite. This time delay is used to determine the distance from the satellite to the receiver. Measurements from four or more satellites are used to calculate the position of the receiver. Although position could be triangulated from three satellites, use of the fourth is necessary to remove errors generated as the signals pass through the atmosphere.

Two different codes are broadcast by GPS; the Precision or P-code, and the Coarse/Acquisition or C/A code. The more accurate and jam resistant P-code is available only to users authorized by the U.S. military. The P-code is now encrypted to prevent unauthorized access, this encrypted version is referred to as the Y-code or as the Precise Positioning System (PPS).

The C/A code is designed to provide all other users with a somewhat less accurate positional capability in order to protect U.S. national security interests. The C/A code is intentionally degraded through the use of a feature called Selective Availability, which introduces a timing bias error into the signal. The resultant degraded signal is known as the Standard Positioning Service (SPS), and is available for any user worldwide.

The purpose of the control segment of the system is to track the satellites and to provide them with updates of ephemeris data. The Master Control Station, which provides the update data, is located at Falcon AFB, Colorado and operated by U.S. Air Force Space Command.[2] Five widely separated unmanned monitor stations collect signals from each satellite and transmit their

computed range measurements to the Master Control Center. These measurements are used to calculate the precise updated ephemeris data.

The users segment consists of receivers that utilize the radio signals broadcast by the GPS satellites to calculate accurate position, velocity and timing measurements. A receiver capable of reading the PPS code can provide positional data within 16 meters SEP (Spherical Error Probable) and velocity measurements within 0.3 feet/second. Positional accuracy for SPS is 100 meters SEP. Time can be measured to within 100 nanoseconds, in fact some countries have adopted the use of GPS to determine their official time.

A great variety of receivers are available today due to the numerous military and civilian applications of GPS. Cost, accuracy, speed of signal acquisition, number of channels, size, and durability are some of the design variables. Most military-use receivers are multiple channel, able to perform calculations from five or six satellites simultaneously, in order to provide fast and accurate positions. The standard DOD handheld receiver, the Precision Lightweight GPS Receiver (PLGR), is a small five channel unit weighing 2.7 pounds.[3]

A method to obtain even greater accuracy from GPS is known as differential GPS. This method involves establishing a fixed GPS reference site that broadcasts a correction signal over a local area to remove the inherent atmospheric timing errors. Using differential GPS, accuracy of less than one meter SEP is achievable. Precise differential GPS surveying systems are available that are capable of an accuracy of within a few centimeters.

MILITARY APPLICATIONS OF GPS

The Global Positioning System is a valuable asset to the military commander, providing a wide range of applications. GPS improved situational awareness, vehicle navigation, and missile targeting and guidance act as force multipliers on the battlefield. Using GPS tools, a commander can utilize limited resources more efficiently while reducing risk to friendly forces. This section will examine some of the military applications that exist today, or will in the near future, and their effect on the operational level of war.

Situational Awareness

The most basic military benefit from GPS is a vast improvement in situational awareness, i.e. knowing ones exact location in relation to other forces and geographic features. Today, any ship, aircraft, ground vehicle, or foot soldier, whether in friendly or enemy territory, can be accurately located relative to an universal grid. In combined and joint operations, all the services can operate using the same geographic reference system, enabling use of closely spaced or supporting operations with a reduced risk of friendly fire casualties. Accurate position and time information can be obtained passively from GPS systems, supporting complex maneuvers and coordination while maintaining radio silence.

This increased situational awareness was demonstrated during Operation Desert Storm, where over 5000 GPS receivers were deployed.[4] There, U.S. troops using GPS receivers were able to determine their location, and successfully navigate across the featureless desert terrain.

Navigation

Much has been written on the navigation benefits realized from the use of GPS, so this will only briefly be discussed here. The accuracy of aircraft and shipboard navigation systems have been vastly improved with the addition of GPS receivers. In a typical installation, the GPS receiver is incorporated with an Inertial Guidance System (INS). This arrangement allows GPS to regularly correct for the drift associated with INS, while the INS provides a backup for GPS should the signal be lost or jammed. This combined use of both an inexpensive GPS receiver and INS provides a degree of safety and accuracy not found in higher quality separate systems.

Air operations benefit from this more accurate navigation system through an increased capability to follow more efficient direct flight paths. The greater accuracy of 3-D location in space as well as bearing and velocity enables closer flight paths and strict adherence to no-fly zones. Differential GPS systems can easily be installed at theater airfields to support poor visibility landings. Many commercial airfields currently utilize differential GPS for Category I landings. The U.S. Air Force has successfully tested GPS aided C-135C transport and S-76 helicopter landings, and is expecting to have a 12 channel PPS receiver in production by late 1997 that would support Category II and III landings.[5]

Ship navigation using GPS is improved in similar ways, allowing the use of more direct routes and narrower channels. Some GPS receivers designed for commercial shipping are now integrated into a bridge system, where mariners can observe a moving image of their ship on a digital nautical chart.[6] In fleet operations the GPS derived locations of companion ships can similarly be electronically plotted to provide an real-time, overall picture of the area of operations.

Missile Guidance

Improvements in missile guidance systems have translated into savings in munitions as well as reduced risk for war-fighters. The utilization of more accurate weapons allows targets to be struck using fewer munitions, from safe stand-off distances, and with less collateral damage. Weapons, such as the Tomahawk Land Attack Missile (TLAM), which rely on terrain matching guidance systems have been improved with the addition of GPS receivers. These more capable versions are able to accurately navigate over featureless terrain and bodies of water, and are more effective at night and in adverse weather conditions. These TLAMs, as well as similarly GPS updated HARM and SLAM air launched stand-off weapons were used by NATO forces against Bosnian Serb targets in September 1995.[7]

The U.S. military has placed an emphasis on technological innovations, such as precision guided missiles (PGM), to offset smaller force levels. The benefit of PGMs over traditional "dumb" bombs was clearly shown during Operation Desert Storm. "Laser and electro-optical guided munitions, such as Paveway bombs and Maverick missiles, represented only 7% of the total munitions expended during the war, yet accounted for a majority of target kills."[8] Current laser guided weapons however, are extremely expensive, are dependent on visibility, and require aircraft loiter time to target the missile.

Since the Gulf War, the U.S. military has focused on a new generation of lower cost, accurate, autonomous weapons that can operate in all weather conditions. These new weapons consist of GPS/INS navigation systems with aerodynamic controls which are incorporated into conventional bombs or delivery systems. The navigation system utilizes targeting data passed from the launching platform to steer the weapon to the target with moveable tailcone fins. These weapons

lack the precision of laser guided bombs, the base versions will have an accuracy of 30-40 feet CEP (circular error probable), but this is sufficient for the majority of targets. Pilots can "fire and forget" the GPS guided munitions from a higher altitude and greater distance from the target than with conventional bombs, with a great degree of accuracy. (Some of these new munitions are described in the Appendix.)

For targets requiring a higher degree of precision than provided with GPS guidance, these munitions may be fitted with optical or infrared terminal seekers. A simpler and more economical method is to use wide area Differential-GPS. Portable, easily deployed GPS stations placed 1000-2000 miles apart will provide a signal that would improve the accuracy of these weapons to less than 25 feet CEP, as well as benefiting any other GPS supported operations.[9]

Other GPS guided weapons are being tested and fielded, including a GPS-guided artillery round with drag and steering controls[10], and each new design will provide the commander with greater capabilities and options. These weapons will provide the services with the ability to destroy targets from a greater distance and with fewer rounds, thereby reducing risk to pilots. Targets in built-up areas or near friendly forces can be hit with less collateral damage or risk of friendly casualties. The GPS guidance has the capability to accurately place munitions day or night, in any weather, and autonomously after release. This capability is dependent on certain factors however; the platform must be equipped with GPS to know the launch point, and the exact coordinates of the target must be known. The first factor is minor, soon all military vehicles will have GPS receivers, the target on the other hand, may be mobile or the precise position may not be known.

Targeting

A potential drawback of GPS guidance and navigation is the requirement for precise target coordinates and mapping products. The accuracy of most current paper military maps is not sufficient for accurate targeting. This is due to a variety of factors such as changes in specifications and quality of source material, as well as the inherent errors in paper maps due to line widths and feature offsets.[11]

The Defense Mapping Agency is currently constructing a worldwide geographic database to better support regional contingencies and digital requirements. Digital maps can be created and displayed in the same geographic datum as GPS derived real-time positional data. In addition to providing an accurate, interactive map of the area of operations, this Geographic Information System (GIS) will provide attribute data for transportation, hydrologic, and cultural features. This will provide targeting coordinates to a commander utilizing GPS guided munitions.

Other methods are available for targeting mobile features or those with inaccurately known positions. One such method involves a forward observer equipped with a GPS receiver and a laser range finder. Using the observers known location with the range and bearing to the target, accurate target coordinates can be determined and radioed back to the base camp or directly to a weapons platform.[12] The Marine Corps program "Forward Observer/Forward Air Controller" (FO/FAC), is working towards the development of a man-portable, lightweight, target identification, acquisition, and data relay system to support this procedure.[13] A variation of this method is being tested that determines range using a directional antenna to capture the reflected GPS signal from the target. This method has the advantage of operating passively, reducing the chance of the observers discovery.[14]

The relative guidance method is an effective targeting procedure utilizing multiple GPS equipped aircraft. A reconnaissance aircraft, from a standoff distance of 100-200 km., using Synthetic Aperture Radar (SAR) locates a target relative to itself. Taking three SAR measurements from in flight the target can be accurately located in three dimensional space. These GPS generated target coordinates are then handed off to a weapon delivery aircraft which launches a GPS guided weapon to the target and exits the area. This method is also effective for suppression of enemy air defenses (SEAD) missions, but for these missions the measurements used for target location are made passively, using the RF emissions from the threat radar.[15]

This procedure could be performed by a single aircraft, that would determine the target location using GPS and SAR, and then launch the attack. The Air Force's GPS-Aided Targeting System (GATS) and GPS-Aided Munition (GAM) for the B-2 stealth bomber is such a system. GATS will determine target coordinates and pass them to the munition, which is then released automatically. GATS/GAM will become operational on the B-2 in July of this year.[16]

There are, however, advantages to the use of the multiple aircraft method. It allows a flexible flight approach for the attacking aircraft, and it allows one stand-off targeting platform to locate targets for several missile delivery aircraft.[17]

Reconnaissance

Timely information about enemy troop movements or other changes in a theater of operations is necessary to support informed decisions and planning. Tactical reconnaissance systems will derive enhanced capabilities in flexibility and positioning accuracy through the incorporation of GPS technology.

Theater commanders today may have the use of some of the new generation of Unmanned Aerial Vehicles (UAV) for battlefield reconnaissance. The UAV would fall under the control of the commander, who could task areas for collection, and directly receive the downlinked real-time reconnaissance imagery.[18] These UAVs, equipped with up to one foot resolution SAR, along with electo-optical and infrared sensors provide capabilities not available from satellites or manned reconnaissance aircraft.[19]

The UAV, with it's multiple sensors can provide imagery at any time, regardless of weather, whereas satellites are only available at certain times, are tasked by many users, and may use sensors that are limited by clouds. UAVs available today are nearly invisible to radar and can stay aloft for up to 60 hours. Manned reconnaissance platforms do not have this same endurance and put aircrews at risk.[20]

New UAVs, such as the medium altitude Predator and the high altitude Endurance, rely on GPS navigation, so they are no longer limited by line of sight controls or relay aircraft. The craft can be programmed before flight, reprogrammed during flight, or operated remotely. When pre-programmed, the UAV will navigate autonomously using GPS signals.[21]

The Army Corps of Engineers is developing a method of determining the actual coordinates of reconnaissance imagery as it is collected. Using GPS derived aircraft location and sensor orientation, the position of a point on the ground can be calculated and incorporated into the image.[22] This capability will be useful for tactical mapping and targeting.

The Army is also developing a projectile shell containing a GPS receiver and a video camera to fire over enemy territory for reconnaissance. The shell would deploy a steerable parachute enabling the user to remotely guide the unit over points of interest. This unit would send back

color video with GPS derived coordinates super-imposed on it.[23] This type of unit could be used for real-time bomb damage assessments (BDA) in high risk areas.

Battlefield Management

Battlefield Management refers to the efficient, timely, coordinated utilization of friendly forces in the theater of operations with minimal risk. This involves the complex task of coordination of joint and combined forces performing a variety of inter-related missions. Building on the situational awareness achieved with GPS, and the communications technology available today, an integrated combat identification (CID) system could provide the commander with a valuable tool for command and control. Such CID systems would give a clearer picture of the battlefield, providing the ability to reduce friendly fire incidents, track asset positions, coordinate supporting operations, and aid in search and rescue missions.

The friendly fire casualties during the Gulf War identified the need for the "positive, timely, and reliable identification of hostiles, friends and neutrals."[24] The Joint Combat Identification Office was established to oversee the development of CID solutions. Their top priority solution is through the use of the Tactical Digital Information Link-Link 16 (TADIL-J), a common datalink enabling a single message to convey GPS derived position, platform identification, and weapons control messages. The use of GPS provides a common grid reference for locating the positions of all military assets.[25]

For the critical air to ground links, a digital radio configuration known as the Situational Awareness Data Link (SADL) is currently being tested by the JCIDO. This will allow pilots to receive real time ground data, and show on a heads-up display the locations of up to five friendlies

closest to a target.[26] The increased awareness of ground troop locations will allow closer air support for troop movements and amphibious landings, and permit GPS guided munitions to be fired from beyond visual range, a restriction imposed on some weapons platforms to reduce fratricide.

Command and control will also benefit greatly from these developments in situational awareness. The Navy has developed a UHF satellite communication system designed to track naval, air, and ground forces, that provides the GPS positions of up to 2000 users. The Saber (situational awareness beacon with reply) utilizes a GPS receiver and UHF satellite communication equipment installed in each vehicle to provide position, altitude, heading, velocity, and platform identification.[27] Utilizing this system, a commander can view a digital map of the theater of operations showing the actual locations of all friendly assets. This system will be able to track and display vehicles in real time, and log the data for later analysis.[28] The real-time situational awareness will support better informed and more timely decisions regarding force utilization and supporting or coordinated missions. A similar system has been used for tracking border patrol vehicles in the former Yugoslav Republics. At an operations center in Berlin, the GPS positions of these vehicles 1000 miles away are accurately monitored.[29]

GPS enhanced survival radios, designed for use by aircrews or personnel operating in enemy territory, can substantially improve the success of search and rescue (SAR) missions. These units combine a small GPS receiver, which can be used for navigation, with a transceiver for ground to air communications. Precise location can be transmitted to a SAR aircraft in a short burst to reduce the chance of hostile detection.[30]

Other Military Applications

There are several other innovative uses of GPS technology that provide improved capabilities for a variety of missions. GPS has applications in supply operations such as shipment tracking and air-drops, mine laying and clearing operations, anti-submarine warfare, and special operations.

Using a method similar to the military vehicle tracking system described earlier, a small GPS receiver and transmitter can be placed with high value cargo to track it's route. The transmitter periodically sends it's GPS derived position through a communications network to the tracer. This method was successfully used to track a shipment of Patriot missiles to South Korea. The progress of the shipment was displayed in real-time on a digital map in the U.S., as the missiles were transported by ship, train, and truck to their destination.[31]

An innovative way of accurately air-dropping supplies also relies on GPS. A GPS equipped aircraft drops a parachute carrying a GPS receiver and transmitter before the supply drop. When the GPS unit lands, it transmits it's location to the aircraft automatically. The drift due to wind currents can be calculated from the known drop point and landing locations, allowing the pilot to determine the drop point needed to accurately deliver the supplies.[32] This capability of improved accuracy for supply delivery will be useful in wartime as well as for humanitarian missions.

Mine locating and clearing operations will utilize GPS to increase their effectiveness. More precise GPS navigation systems on the mine-clearing vehicle as well as on the ships traversing the swept channel will allow safe passage of a channel 20 times narrower than with the use of Loran-C radio-navigation.[33] GPS assisted mine laying operations will allow precise mine placement, providing the ability to place a tighter mine network, and still provide channels for friendly ships.

Sonobuoys, used to receive acoustic signals and transmit them back to an anti-submarine warfare (ASW) aircraft, can also benefit from GPS enhancement. ASW aircraft use the signals received from multiple sonobuoys to determine the location of submarines. The Tidget, an inexpensive (about $75) GPS tracking sensor, placed on the sonobuoy will provide the aircraft with the exact positions of the sonobuoys. This will allow more precise calculation of submarine position, increasing the accuracy of a torpedo attack.[34]

The Tidget sensor can also be used on balloon carried radio-sondes to double the accuracy of wind speed measurements over current methods to 0.2 meters/second. The GPS radio-sonde will directly measure wind speed and direction, and balloon altitude to support upper atmosphere weapons systems.[35]

The passive operation of lightweight and accurate GPS receivers make them invaluable for use by special forces for navigation and locating rendezvous points. GPS signals however, do not pass through water which limited their use by combat swimmers. The Miniature Underwater GPS Receiver (MUGR) system was designed specifically for such use. The system, which can be used down to 30 meters, includes a CO2 inflatable surface buoy containing an antenna. The swimmers display screen shows current position and tracks waypoints. If the swimmer encounters a significant object, such as a mine, the precise location can be stored by simply pressing a button.[36] The MUGR has completed operational testing by the U.S. Navy SEALs, and should be currently available. The 10 oz. pouch carried unit will also be used for land navigation, and can calculate target coordinates using range and bearing obtained using a laser range finder.[37]

GPS RISKS AND LIMITATIONS

The two greatest risks faced by the U.S. military regarding GPS are the loss of use of the system and enemy use. Loss of use could be from destruction of a portion of the system or from jamming of the signals. Enemy use of GPS could give an innovative enemy similar capabilities for GPS guidance and navigation that U.S. forces employ. There are also physical limitations to the universal availability of the GPS signals. This section will examine these risks and limitations and the issues involved in finding solutions.

System Integrity and Jamming

The destruction of some of the satellites or the ground stations would either partially or totally disable the system. This would be disastrous not only for the military but also for the millions of civilian users worldwide. Clearly great security measures must be employed to protect these valuable assets. The satellites have been designed with hardening against laser attack, and onboard sensors to laser illumination or collision. Presently few nations have the ability to destroy a satellite almost 11,000 miles above Earth, and the central control station is relatively safe in the Continental U.S. In the near future there is a low probability of an attack on the physical structure of GPS.

The loss of full GPS capability due to jamming is a far more likely contingency. The relatively weak signal received at the earth's surface can be quite susceptible to enemy jamming. Reports that low power, inexpensive jammers can defeat unprotected receivers have elicited great concern over the reliance on GPS for missile guidance. Jamming resistance is built into all military

receivers and the PPS signal is also designed to resist jamming, but this is still a real threat and further improvements are being developed. (See Appendix)

The GPS receiver is most susceptible to jamming prior to initial acquisition of the signal. Once the signal is acquired, the receiver is far more resistant to a high jamming environment. For this reason fast signal acquisition, when the missile is furthest from the target is preferred.[38] Receivers are available today that can acquire a GPS signal within one second of launch despite dynamic maneuvers.[39]

In addition to anti-jamming technology, the close integration of a GPS receiver with an inertial guidance system prevents jamming from completely negating the guidance system. Jamming is a threat that is localized near high value targets, if the GPS signal is lost close to the target, INS will provide accurate final guidance.[40]

Enemy Use of GPS

There is a clear danger that the U.S. will face an enemy with the capability to utilize GPS for military uses including missile guidance. Due to the joint civil/military design of the system, the availability of GPS hardware and technology is exploding to keep pace with civilian demand. The technology is readily available for an enemy force, or even a terrorist organization to build a GPS guided medium or long range cruise missile, or a UAV capable of dropping munitions at a programmed GPS drop-point.

The selective availability of the SPS signal reduces the accuracy of GPS guidance to 100 meters CEP, but if a NBC (Nuclear, Biological, or Chemical) warhead is used, or if a densely populated area is targeted, this accuracy is sufficient to cause devastating damage. Readily

available differential GPS systems can also be used with the SPS signal to provide accuracies comparable to the use of the military PPS signal.

To protect against unauthorized use the PPS signal is encrypted and PPS receivers as well as receivers capable of operating in a highly dynamic environment, such as missile guidance, are tightly controlled by the U.S. Defense Department. These controls must continue to be strictly enforced, but this will not eliminate the problem. The U.S. does not have a patent on technology, other countries certainly have the capability to build GPS receivers that can withstand high G-forces.

In a high threat wartime situation the Defense Department has the ability to further degrade or disable the SPS signal and still retain use of the PPS signal for their own use. However, with the explosion in civilian use including commercial airlines (the FAA has accepted GPS as their standard navigation system) and the growing international dependence on GPS, it would be politically impossible to disable the system.

One possible method to limit enemy use of GPS would be to regionally disable the SPS signal in a war zone. This solution would be effective for regional conflicts and would minimize the loss to worldwide commercial users.[41]

Physical Limitations

A final limitation of GPS that primarily affects ground operations, is the inability to constantly maintain visibility of the four satellites required for optimum results. Conduct of operations in urban areas or heavily wooded terrain may place the warfighter into positions where GPS signals would be blocked by tall buildings or forest canopy. Severe weather conditions such as

sandstorms may also temporarily affect signal acquisition. Loss of signal contact could also affect low flying missiles or aircraft temporarily blocked by the terrain from one or more satellites.

The solution to this is in the same tightly coupled GPS/INS system that is effective against local area jamming. The inertial guidance will maintain a relatively accurate position for a short period of time until the GPS signal can be reacquired.

CONCLUSION

The Global Positioning System generated a revolution in the application of geographic science by providing constant, worldwide, accurate measurements of position and time. This capability has fueled a flood of innovative military and civilian uses for the system. To the military, GPS is a valuable, force-enhancing tool that has applications over a wide variety of missions.

GPS will have a significant effect on force utilization to the operational commander. Improvements in situational awareness, navigation, and reconnaissance will greatly reduce the fog of war by providing a clearer representation of the battlespace. GPS-guided weapons can accurately and economically destroy targets, while reducing pilot risk. These applications and others have been discussed in this paper to acquaint the reader with the range of operations that will benefit from GPS. In the future there are certain to be new and inovative applications, and improvements to existing ones. There are risks and limitations associated with the system that must be understood and controlled, but they are far outweighed by the gains realized from GPS.

The successful commander must understand both the broad capabilities and the limitations of GPS to effectively utilize this new technology to it's fullest potential on the battlefield. In the years ahead, all U.S. warfighters will benefit from the many applications of GPS technology.

APPENDIX

A SAMPLING OF GPS GUIDED WEAPONS

The Joint Direct Attack Munition (JDAM) is a GPS guided tail kit that attaches to Mark 80 bombs to make 1000lb. (MK-30) or 2000lb. (MK-29) smart bombs. The tail kit uses GPS targeting data to guide the bomb with controls that deflect the moveable tailcone fins.[42] JDAM has a accuracy of 30-40 feet CEP and can glide 12 miles when dropped from 30,000 feet or higher. These bombs will equip aircraft that do not carry designators for laser guided bombs, including the B-1, B-2, and B-52. The first deployable JDAM capability is planned for late 1997 with a approximate cost of $18,000 each, and the B-1B and B-2 aircraft could also be equipped for the GPS guided bombs during 1997.[43]

The U.S. Navy's and Air Force's Joint Stand-Off Weapon (JSOW) is a GPS/INS guided glide bomb with a range of over 40 miles, and a capability to carry a variety of munitions. One version, planned for year 2000 availability, will contain six BLU-108 sensor fused weapons, armed with anti-armor submunitions. The Navy's unitary JSOW will be equipped with an imaging infrared terminal seeker and will carry a BLU-111 500 lb. warhead. The unitary JSOW, with a 10 foot CEP, will be used against point targets such as bridges. JSOW is planned to be used on the Navy F/A18, Marine AV-8B, and Air Force F-16. The base JSOW will cost around $100,000, and the more precise unitary version around $400,000.[44]

Another weapon worthy of mention is the Air Force's Wind Corrected Munitions Dispenser (WCMD). This is a cluster bomb dispenser fitted with a GPS guidance system which will correct for errors caused by wind direction and velocity. The WCMD can only glide a few miles, but it can be released from an altitude of 40,000 feet, above the range of many air defenses. As with

JDAM this $25,000 weapon basically consists of a guidance tail kit that is fitted to an existing tactical munitions dispenser. The WCMD can carry a variety of submunitions including Sensor Fused Weapons, and Gator mines, and is expected to be a very effective weapon against mobile theater ballistic launchers.[45]

RECEIVERS RESISTANT TO JAMMING

A receiver with no anti-jamming enhancements can be jammed at a range of up to 4.5 kilometers by a single watt jamming source. A GPS receiver capable of resisting 40 dB jamming to signal (J/S) ratio is resistant to jamming by a 1000 watt jammer to within 1.5 km. of the source. Current military GPS receivers are resistant to jamming up to a 54 dB J/S ratio. The USAF goal for their anti-jam GPS/INS receiver is to be able to acquire signals in a 75-85 dB J/S jamming environment and to maintain acquisition in a greater than 120 dB environment. As these more jam-resistant receivers become available, it is imperative that the technology be added to military guidance systems.[46]

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